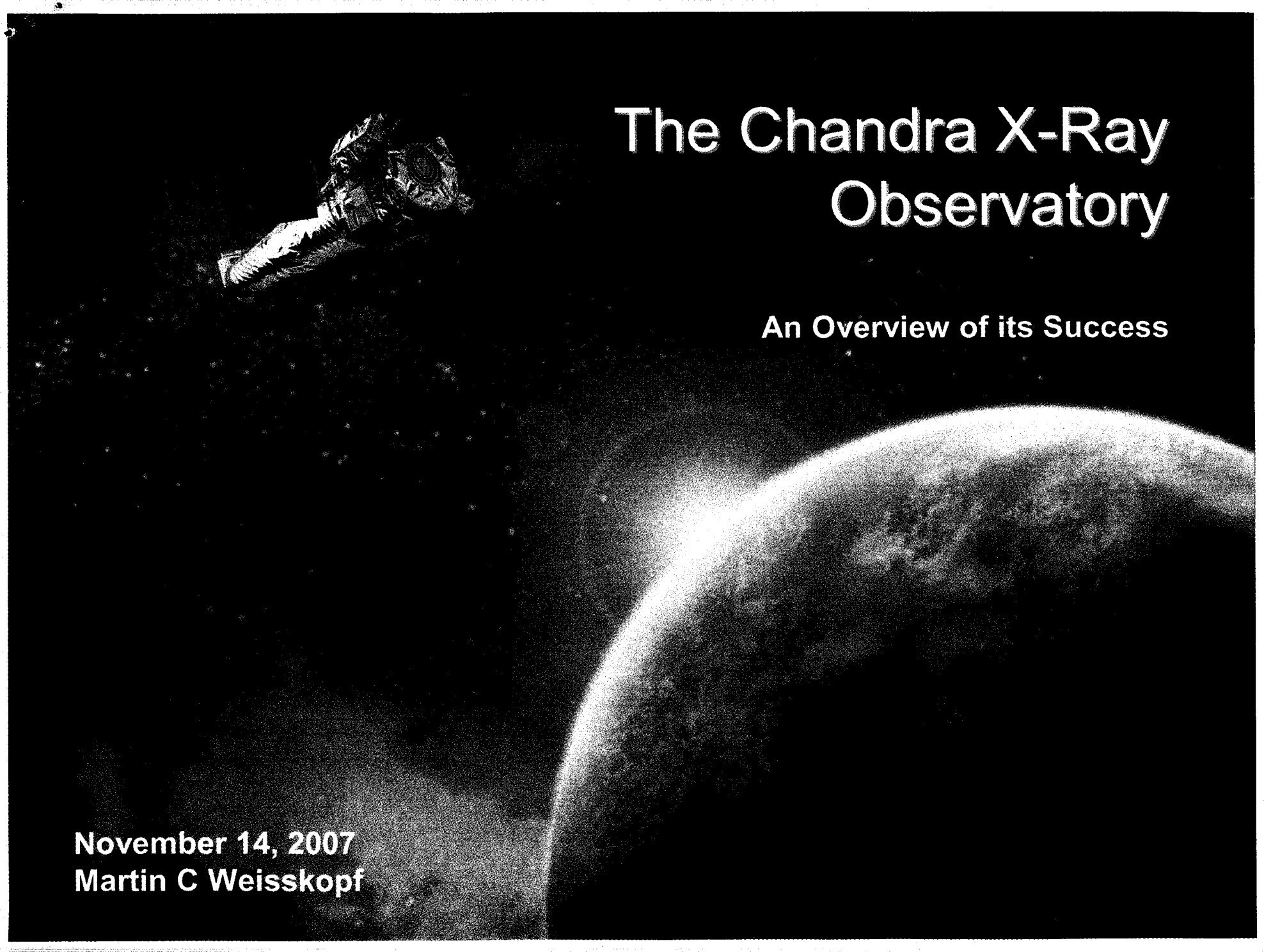
My title is: "The Chandra X-Ray Observatory"

My Abstract is: The Chandra X-Ray Observatory, the X-Ray component of NASA's Great Observatory Program has been an outstanding scientific and technical success. Designed for a three year lifespan, Chandra is now beginning its 8-th year of scientific operation. Some of the history of the Project, including a discussion of the design, development, and calibration of the X-Ray optics will be presented. Of course the highlights of several of the myriad discoveries will be shown concerning topics ranging from solar system objects to dark matter studies in clusters of galaxies.

MSFC-583_Presentation



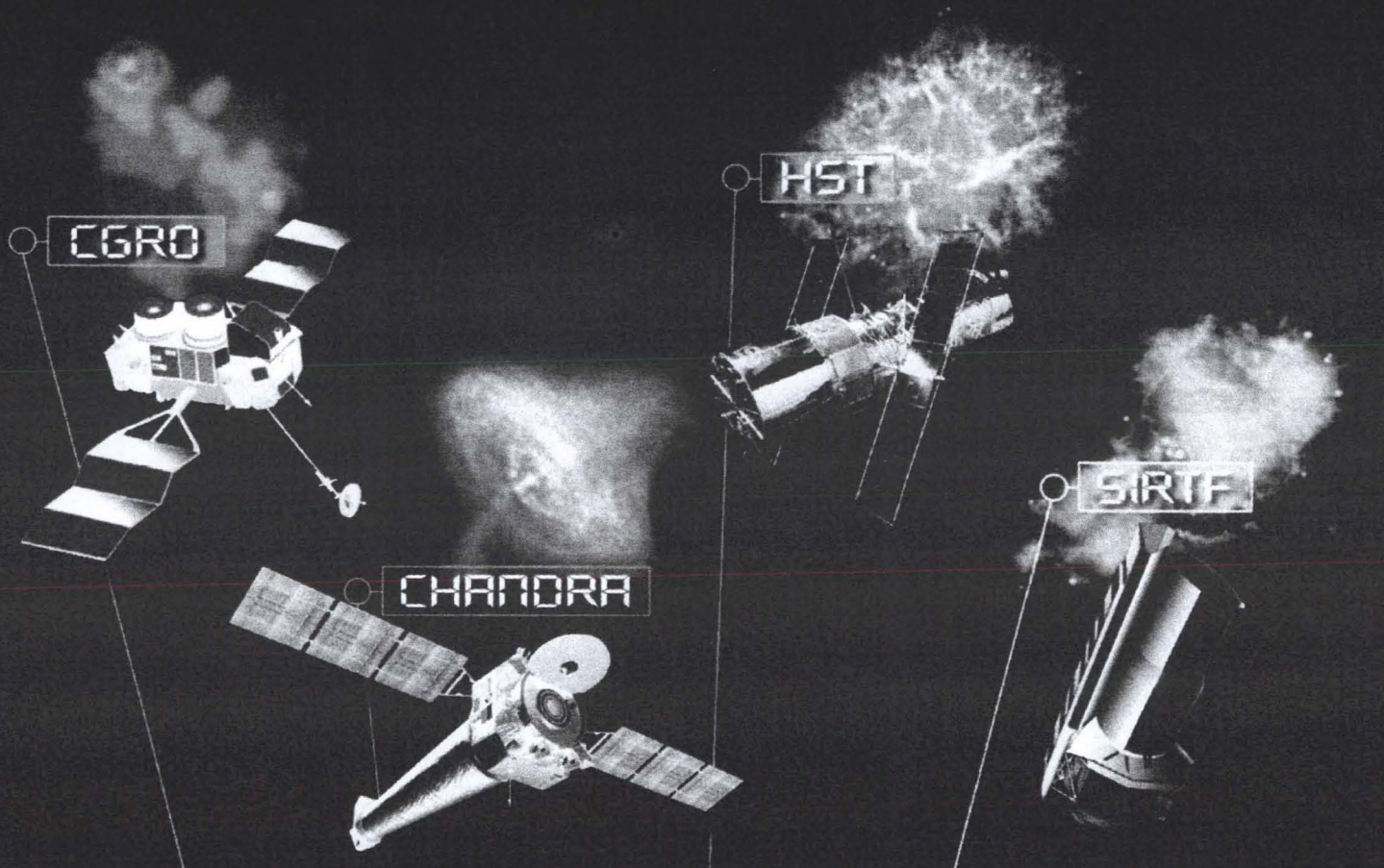
# The Chandra X-Ray Observatory

## An Overview of its Success

November 14, 2007

Martin C Weisskopf

# The Great Observatories



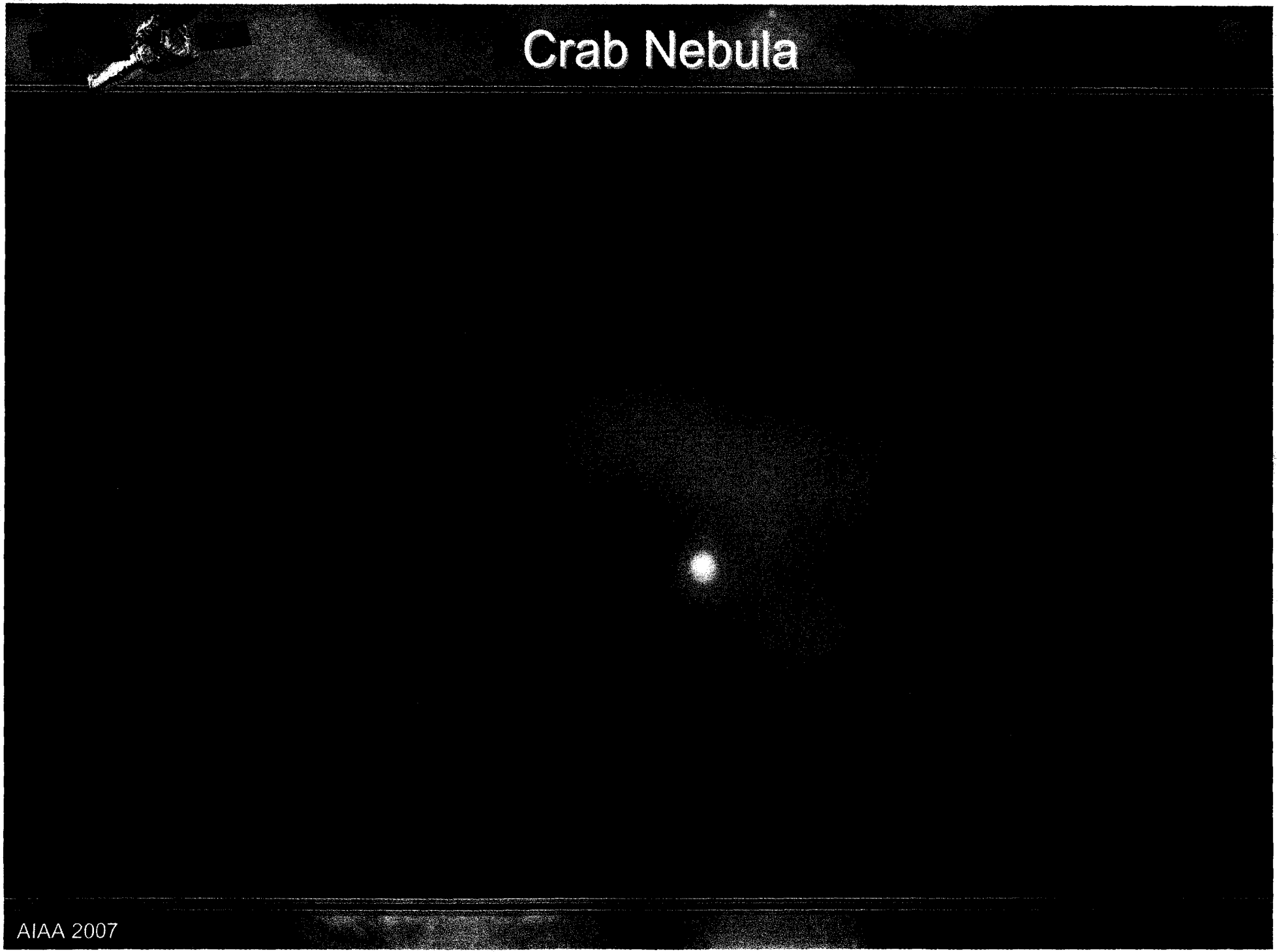

| | gamma | x-ray | visible light | infrared | |
|---|---|---|---|---|---|
| WAVELENGTH | 0.0005 | 0.5 | 500 | 10,000 | 5,000,000,000 nanometers |
| ENERGY | 2,480,000 | 2,480 | 2.48 | 0.124 | 0.000000248 electron volts |

# Chandra History Overview

- 1976: Program start
  - MSFC/SAO Collaboration selected by HASA HQ
- 1985: Instrument selection
- 1988: New Start

- 1999: Launch

# Crab Nebula

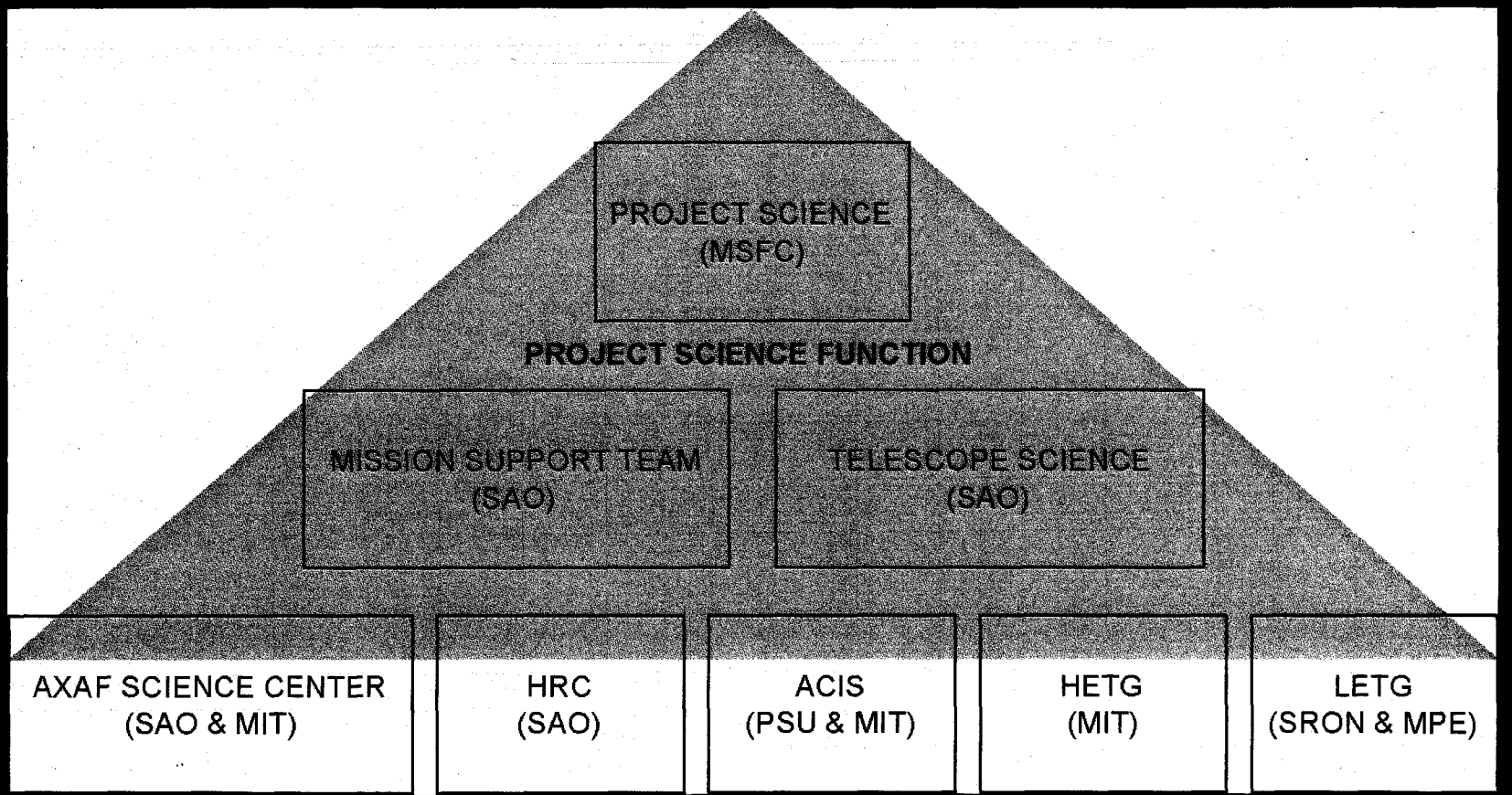


# Recipe for Success

- Team effort
- Science-driven requirements
  - Project Science Team
- Stability of requirements
- Technology programs
- Calibration program

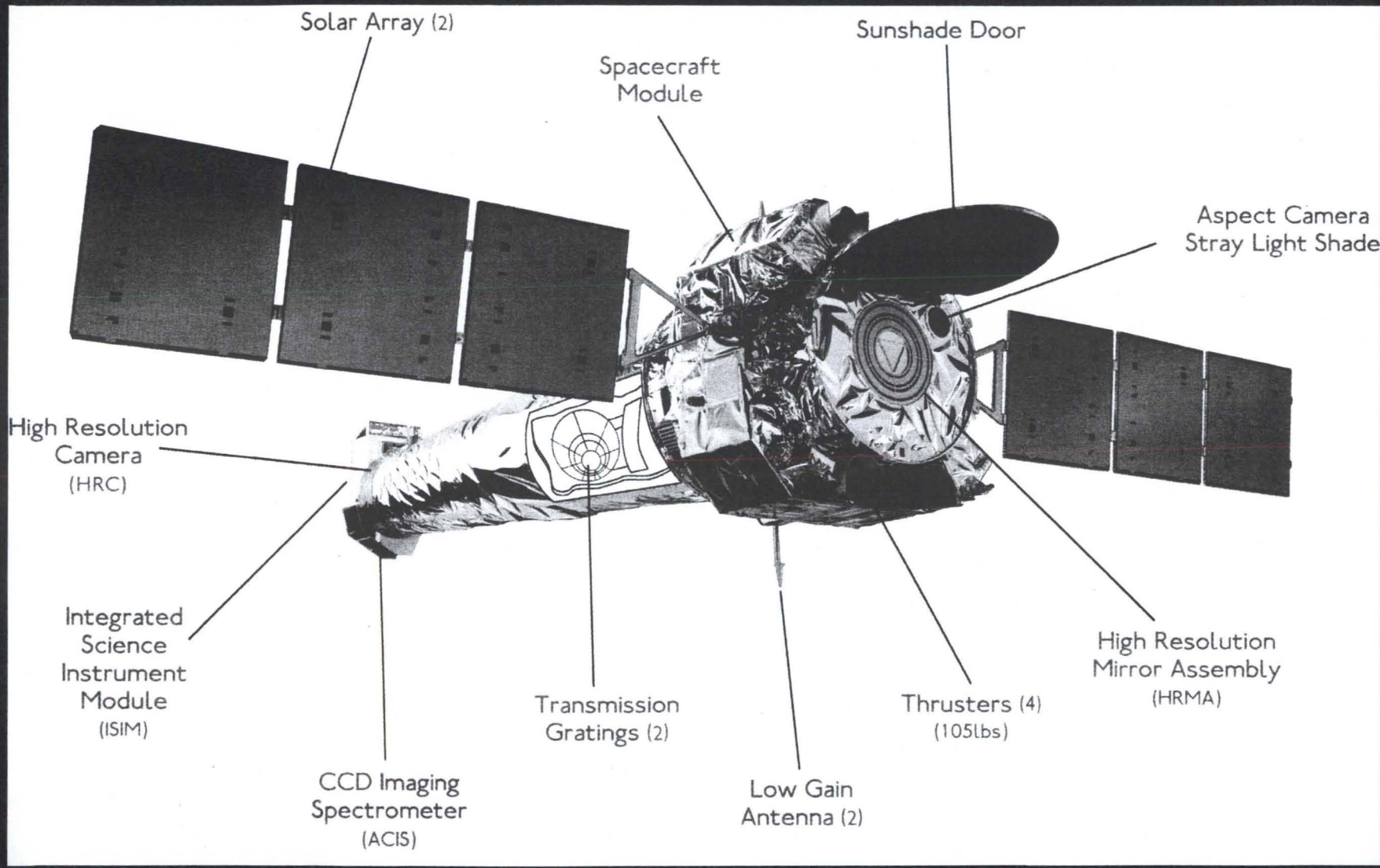
# Project Science

- More than a single person




- On all review boards --- to level 3

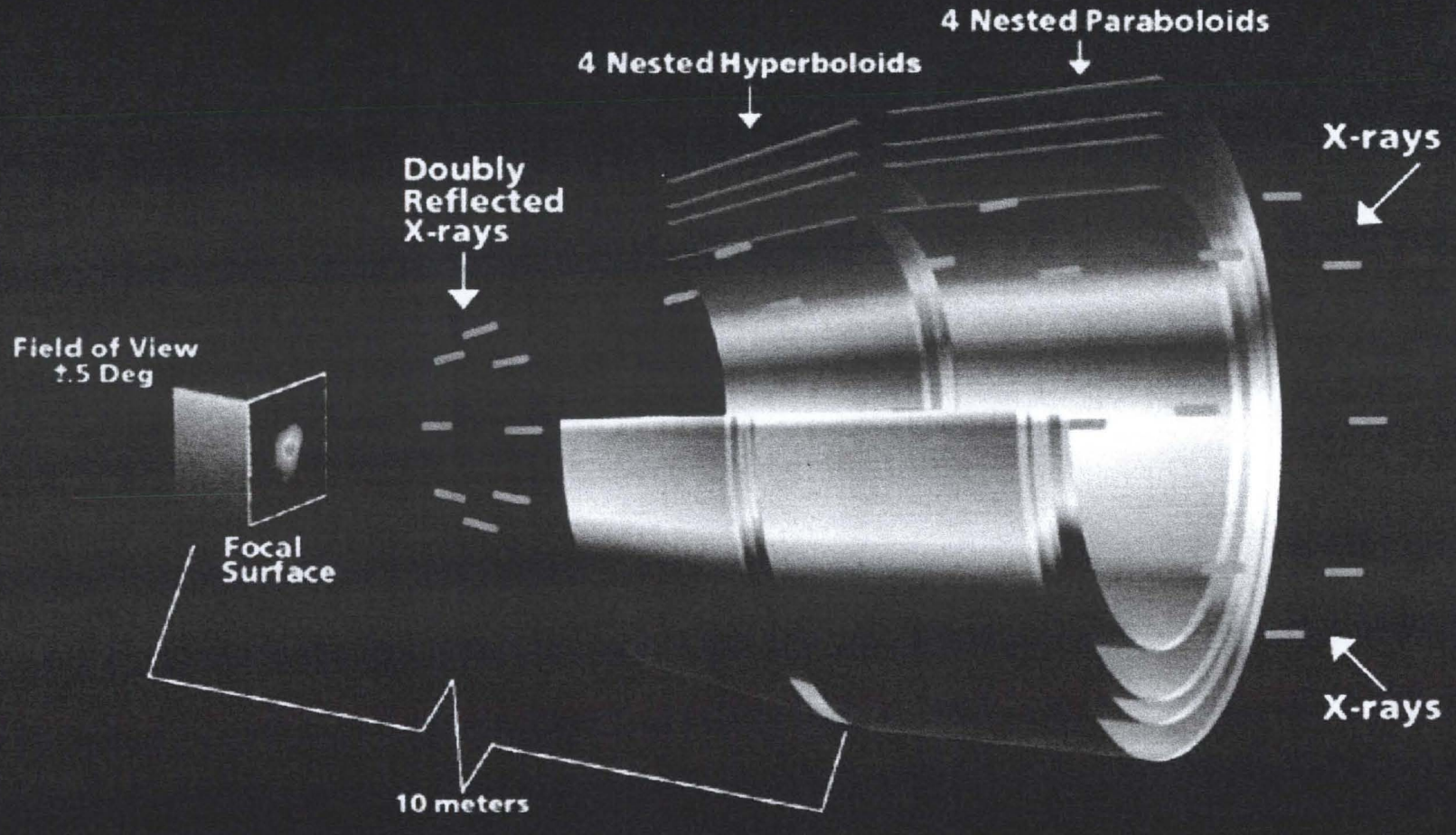
# The Observatory



# Project Sciencs

- More than a single person
- On all review boards to level 3

# Chandra Optics




Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter

# The Beginning - 1976

- 1976 – Proposal was submitted
  - This was the "formal" beginning

PROPOSAL TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOR THE

STUDY OF THE 1.2 METER X-RAY TELESCOPE

NATIONAL SPACE OBSERVATORY

(Volume I - Technical Proposal)

P605-4-76

For the period 1 July 1976 to 30 September 1978


Principal Investigator
Dr. Riccardo Giacconi
Associate Director for
High-Energy Astrophysics Division

Co-Principal Investigator
Dr. Harvey Tananbaum

Co-Investigators
Dr. P. Gorenstein
Dr. R. Harnden
Dr. P. Henry
Dr. E. Kellogg
Dr. S. Murray
Dr. H. Schnopper
Dr. L. VanSpeybroeck

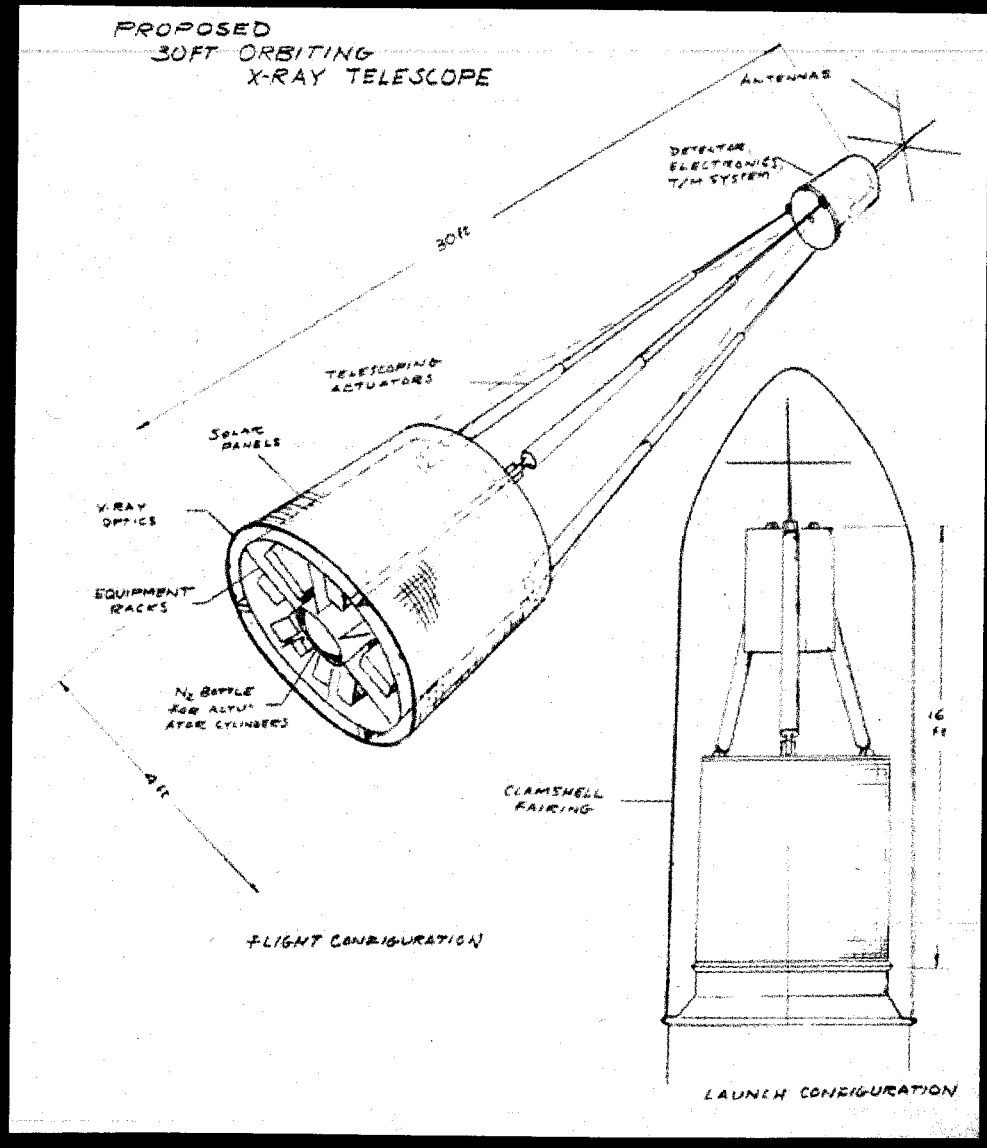

April 1976


Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

Director: Dr. George B. Field  Assistant Director: Mr. John G. Gregory


The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
Center for Astrophysics

# The Real Beginning - 1963




A Proposal for

AN EXPERIMENTAL PROGRAM
OF EXTRA-SOLAR X-RAY
ASTRONOMY

Prepared for

National Aeronautics and Space Administration
Washington 25, D. C.

Prepared by

American Science and Engineering, Inc.
11 Carleton Street
Cambridge 42, Massachusetts

25 September 1963

Approved:

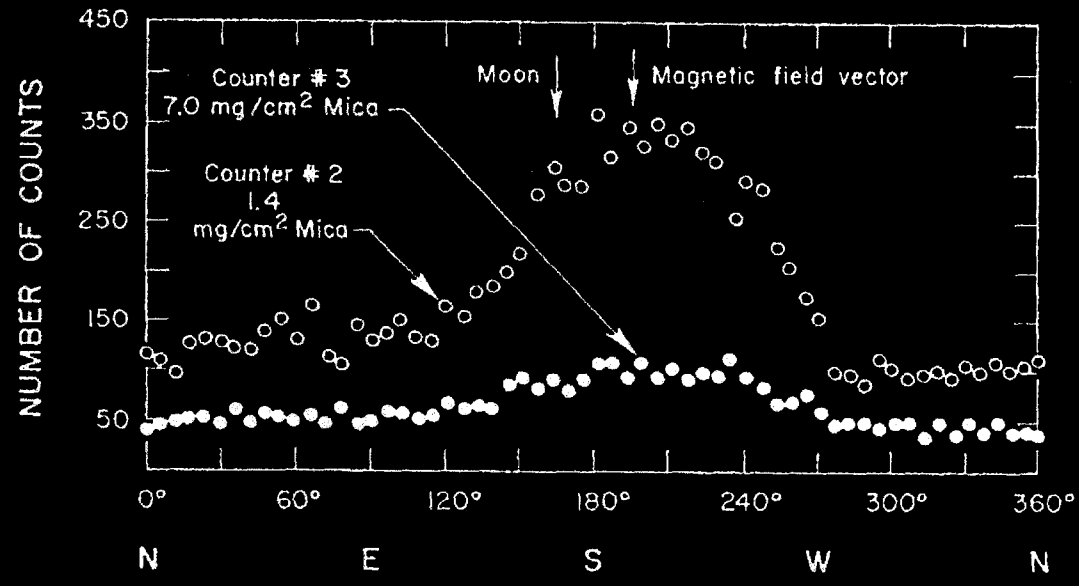
This document consists of 45 pages.
Copy No. 4 of 7 Series A

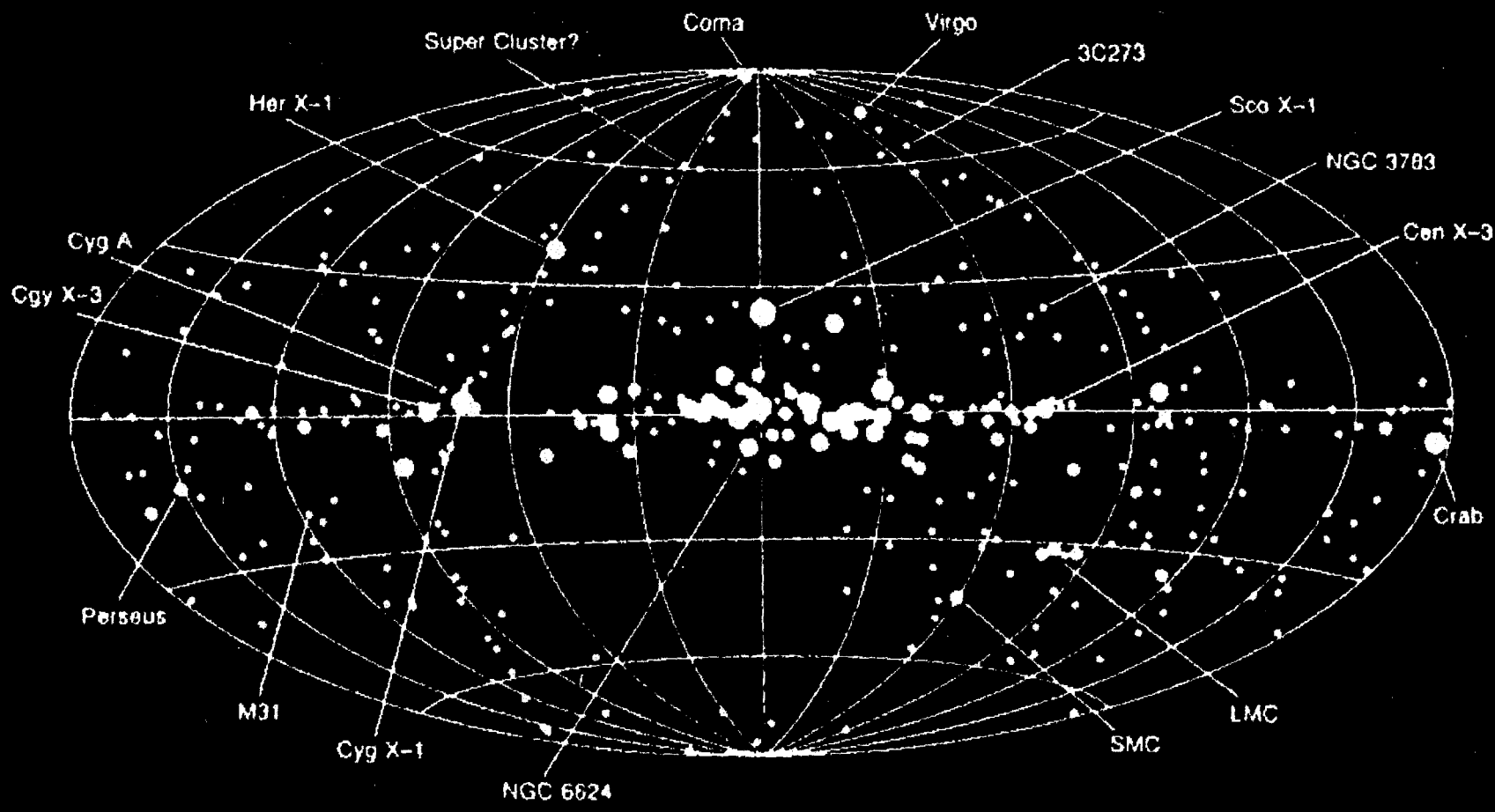
Riccardo Giacconi
Vice President
Space Research and Systems Division

ASE Log No. 63-104-4

# X-Ray Astronomy

- Solar Studies in late 40's
  - Solar corona produces X-Rays
- Discovery of first extra-solar source in 1962
  - Also discovery of faint glow - the "diffuse" background



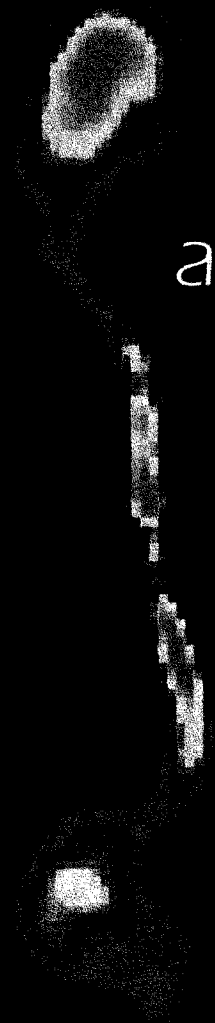



# Uhuru (SAS-1) Conducted the First All Sky Survey of Cosmic X-Rays in 1971

# X-Ray Astronomy

- We now know that most of the matter that we "see" is visible to us from its X-Ray emission
- The bulk of this matter is hot, X-Ray-emitting, gas in the great galaxy clusters

# The Third Decadal Survey - 1981



## Astronomy and Astrophysics for the 1980's

VOLUME 1:
Report of the Astronomy Survey Committee

## Major New Programs:

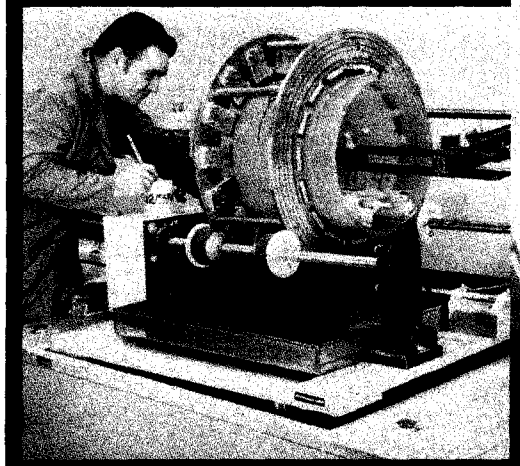
### #1: An Advanced X-Ray Astrophysics Facility (AXAF)

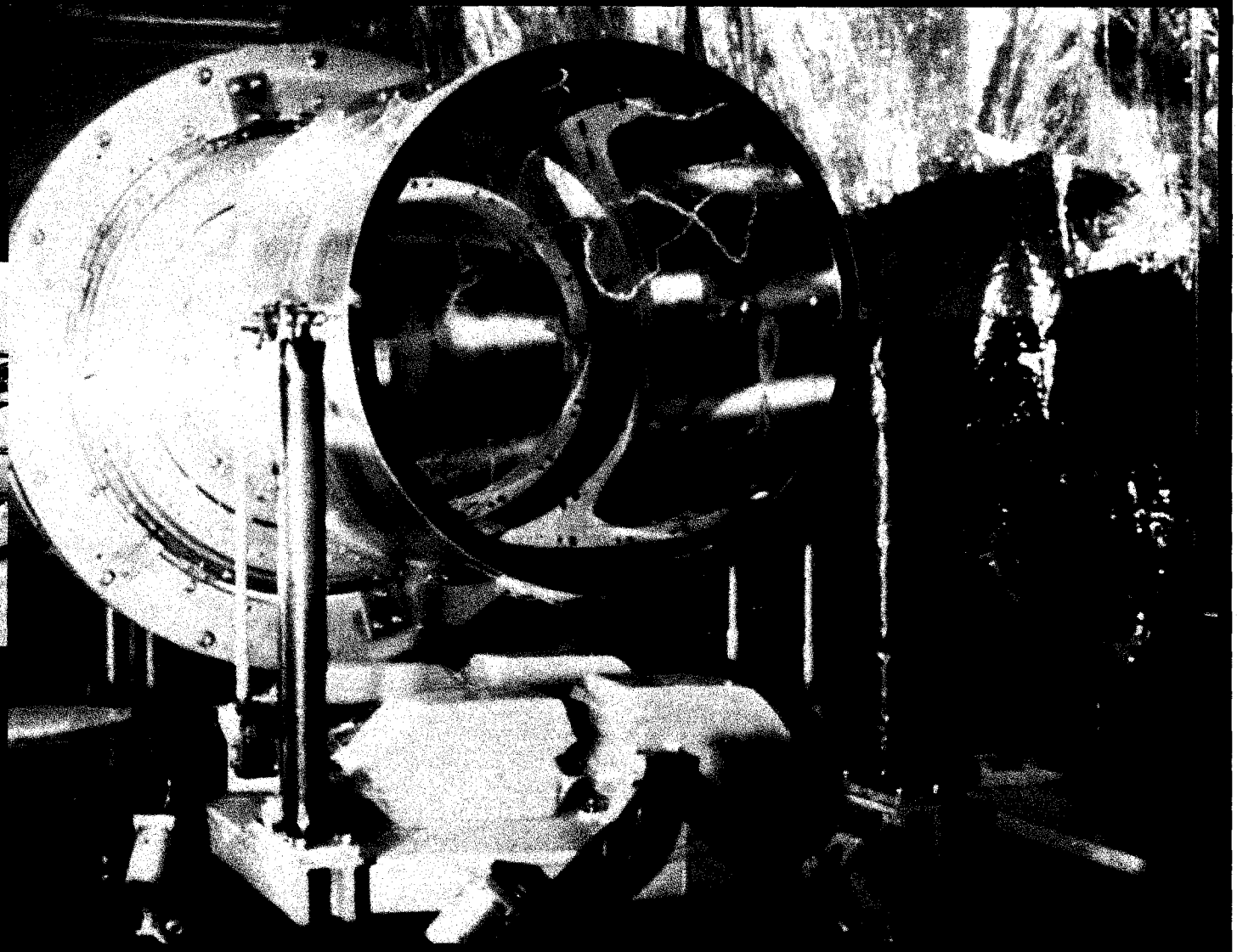
NRC NAS NAE IOM

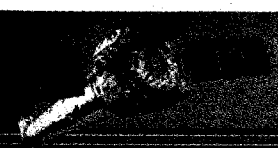
# The Technology Mirror Assembly

- Single mirror pair
- Scaled (2/3) Version of innermost mirrors
- 6-m focal length
  - Allowed for testing in existing test facility
- 0.41-m element length
- 0.42-m diameter
- Gold coated (baseline at the time)

# The Technology Mirror Assembly





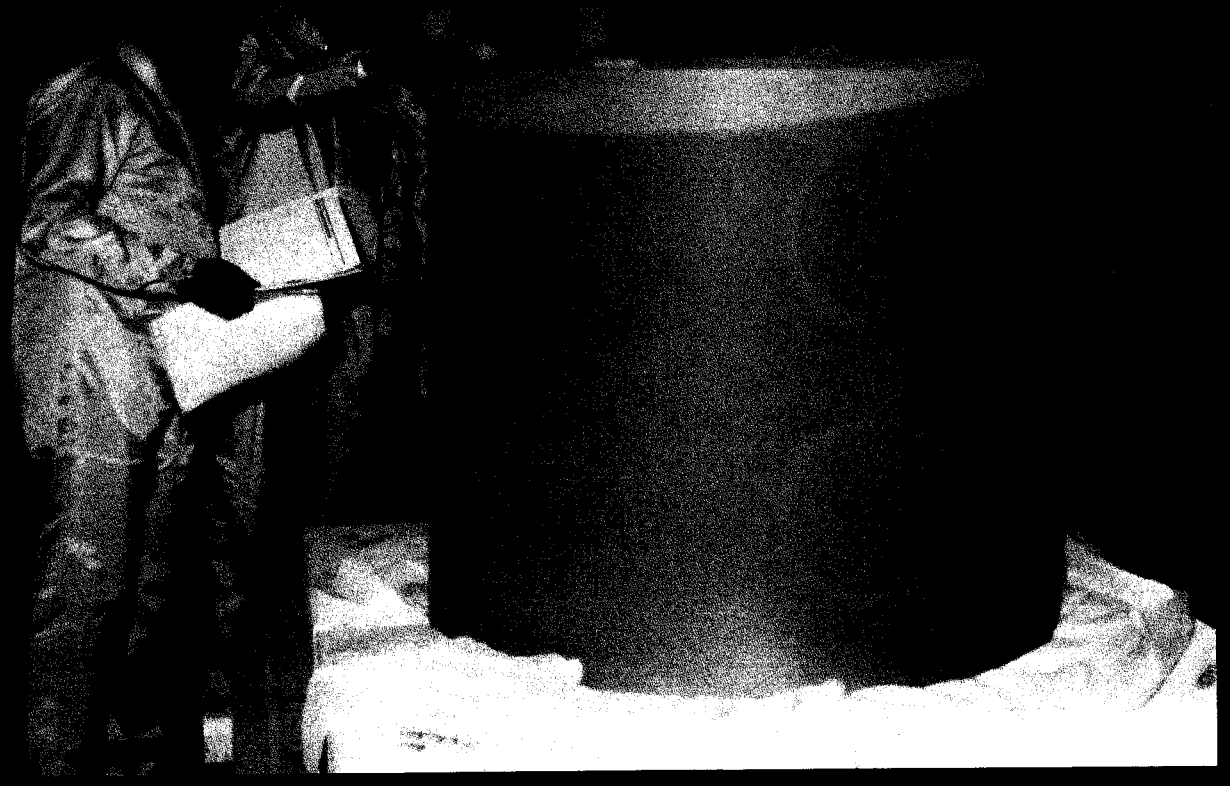


# The Technology Mirror Assembly

- First delivery July 1985
  - Resolution better than 0.5”
  - However, near angle scattering
- Second delivery Jan 1989
- Final results were great
  - E.g. FWHM from 0.36” – 0.68”
  - Encircled energy as predicted

# Flight Mirror Blanks

- Initiated purchase in 1987

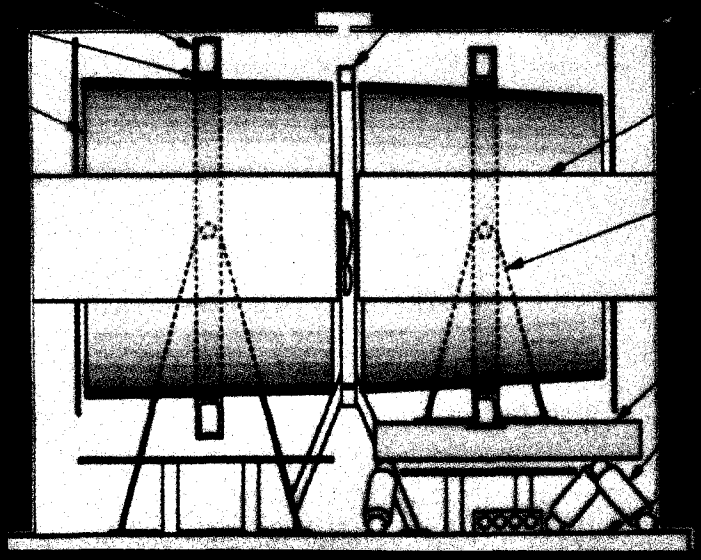


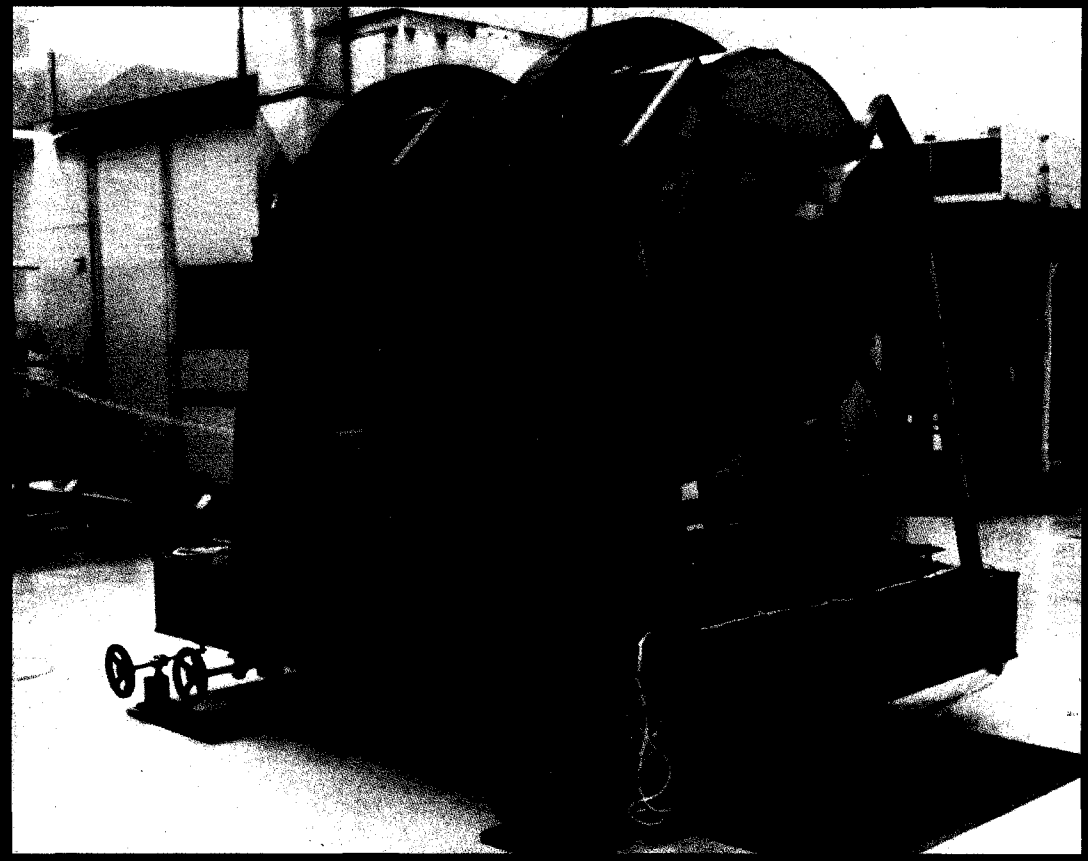
# Other Milestones

- Prime contractor selection – 1988
- "New Start" - 1988
- Selection of the Science Center – 1991
- Started the "VETA" program - 1988
  - Verification Engineering Test Article

# VETA

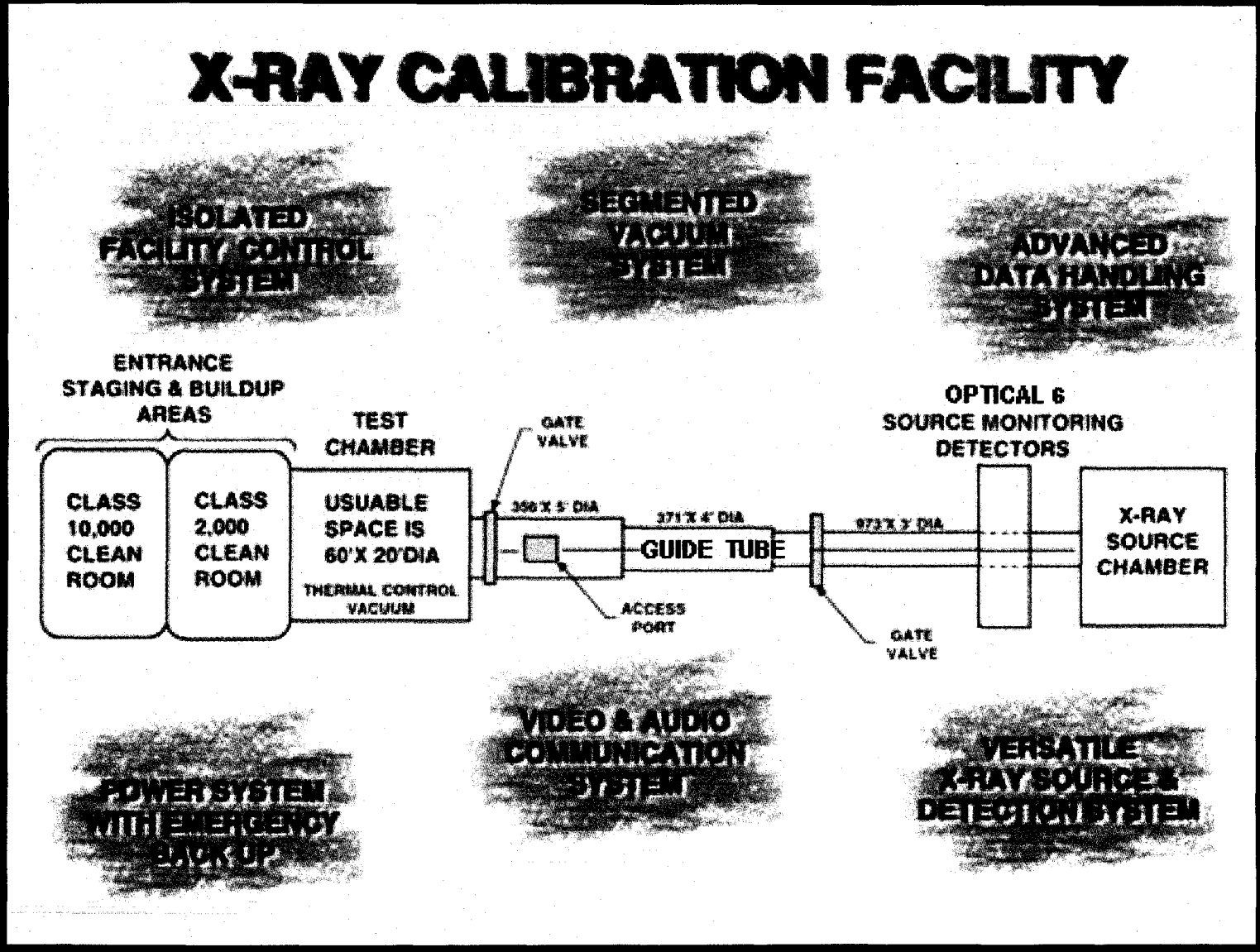
- P1/H1 – uncoated and uncut





- Needed test facility at least one year earlier than planned!

# The X-Ray Calibration Facility (XRCF)



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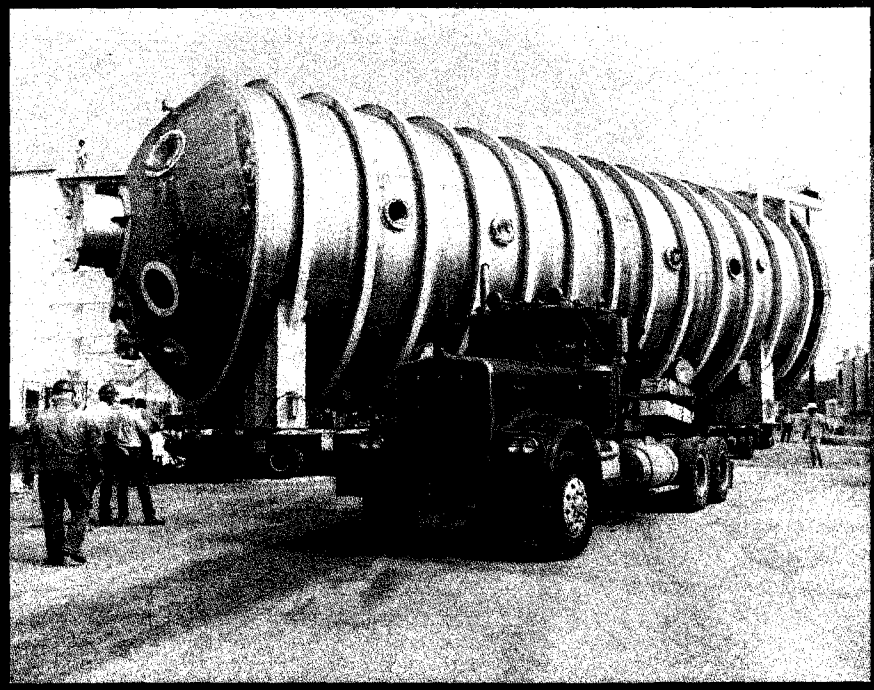
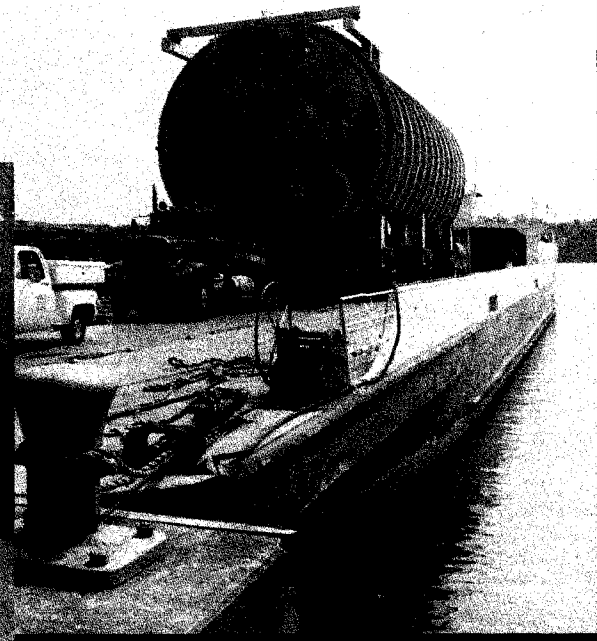
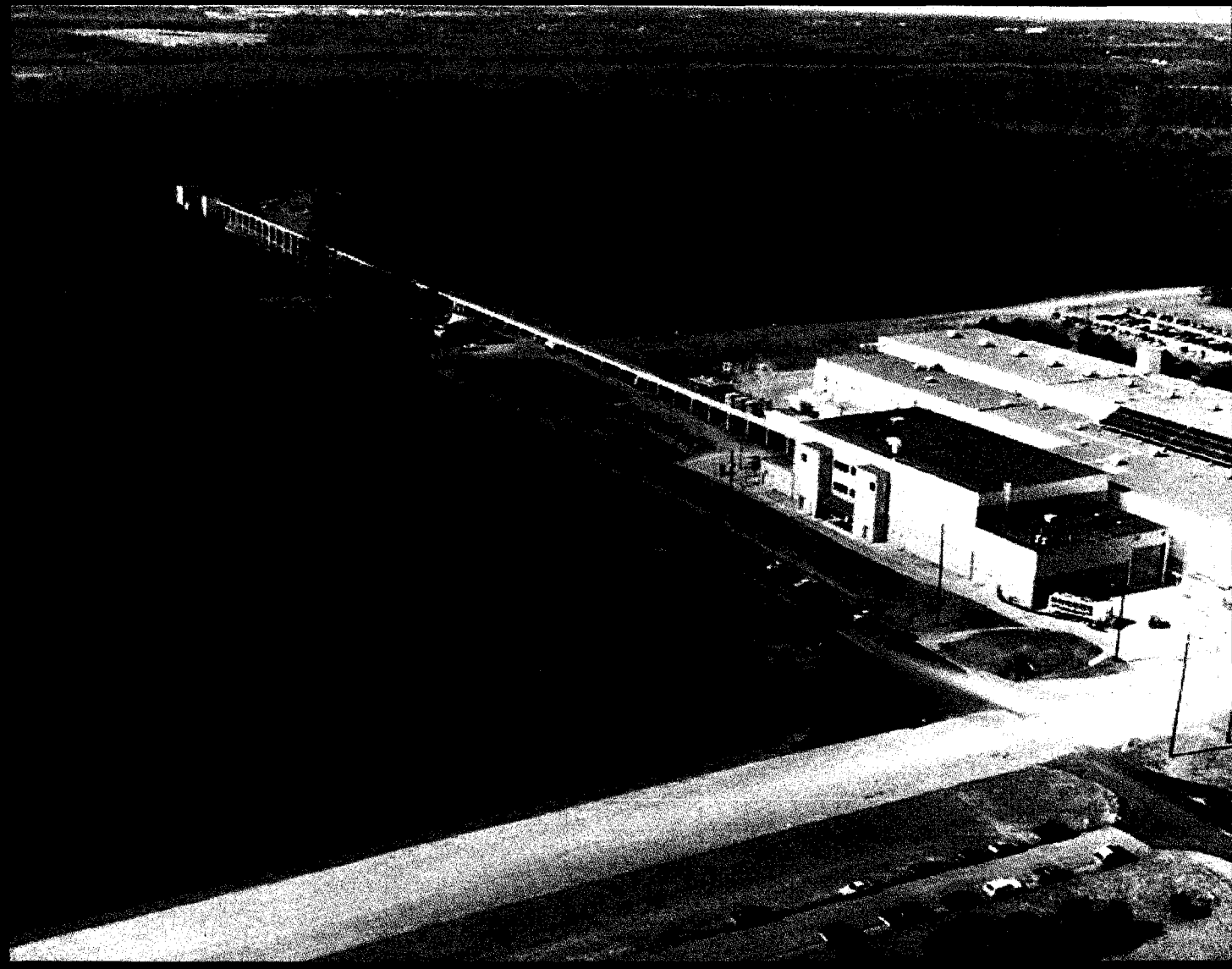
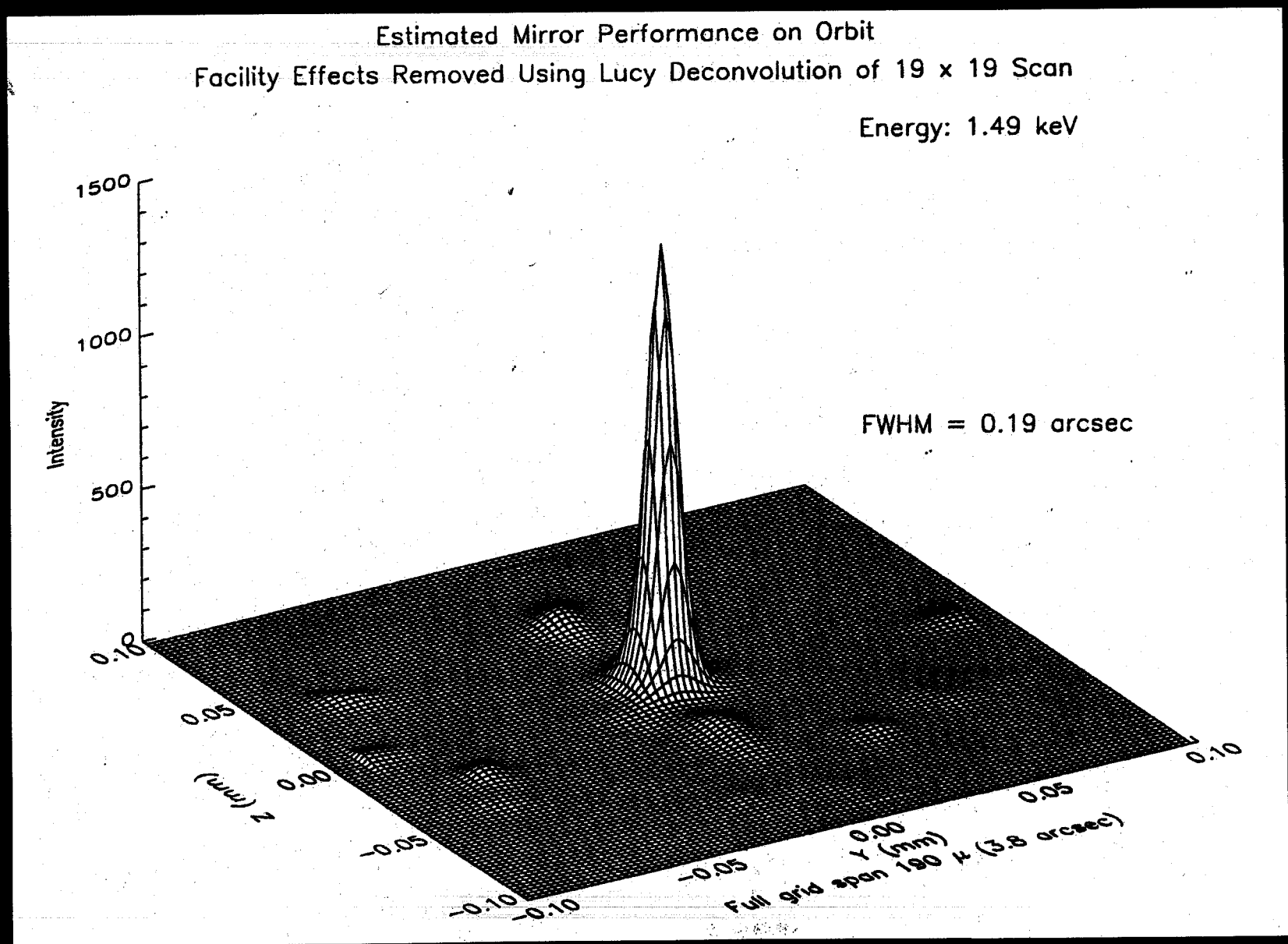




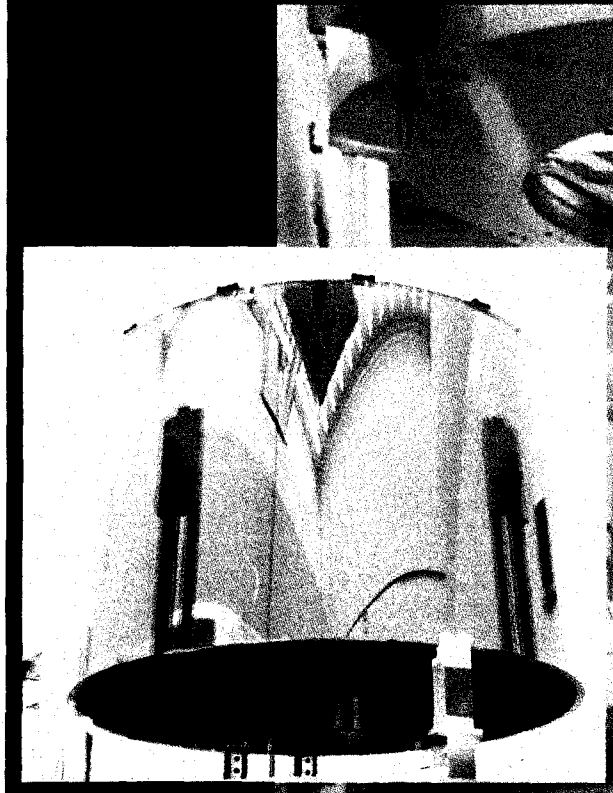
# The X-Ray Calibration Facility (XRCF)

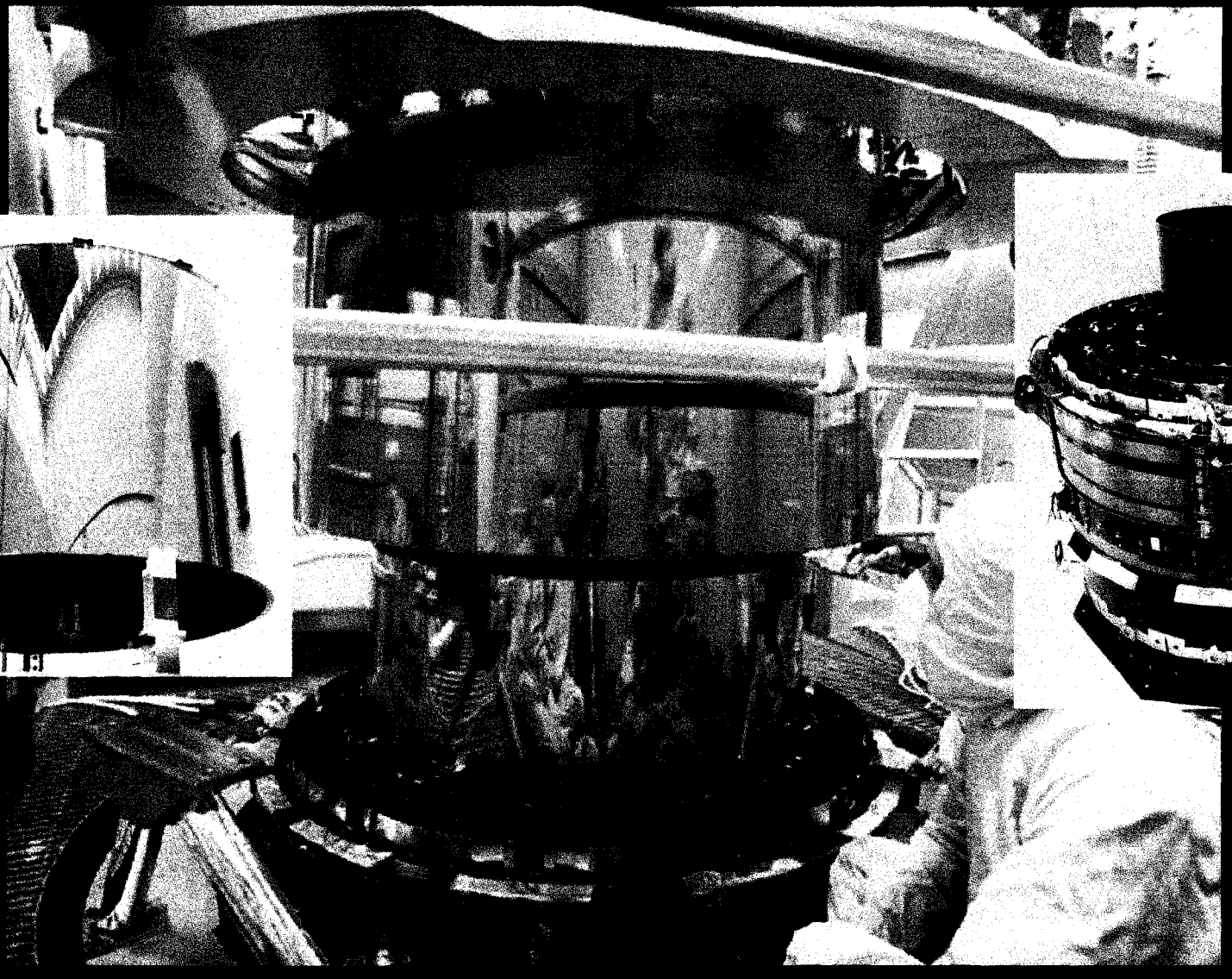


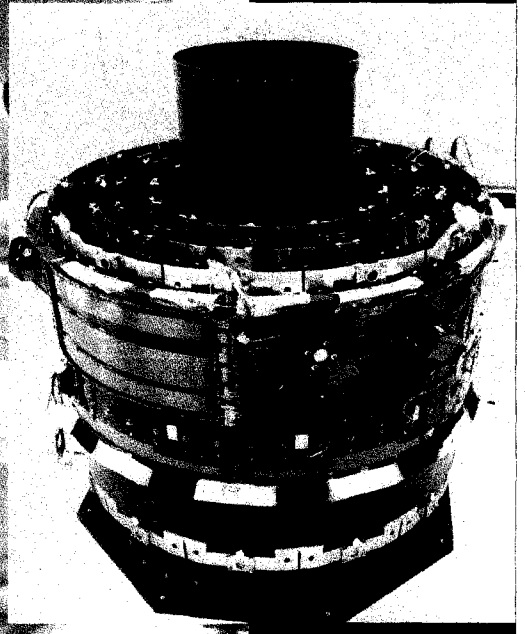
# The Veta Tests - 1991



# Telescope



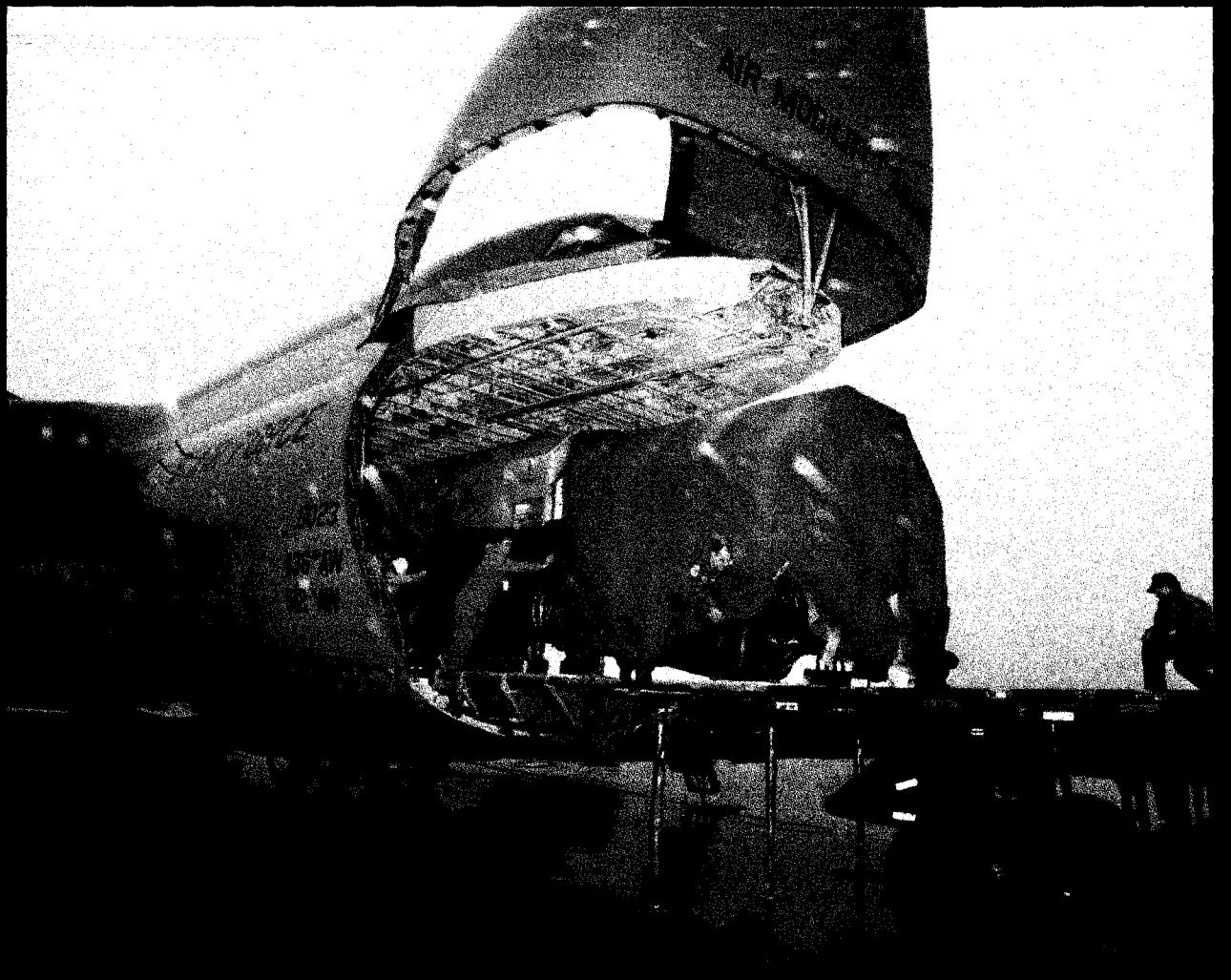


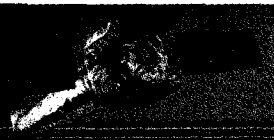


# Calibration Program

- 6 months at the X-Ray Test Facility

# X-ray Calibration (1996-1997)

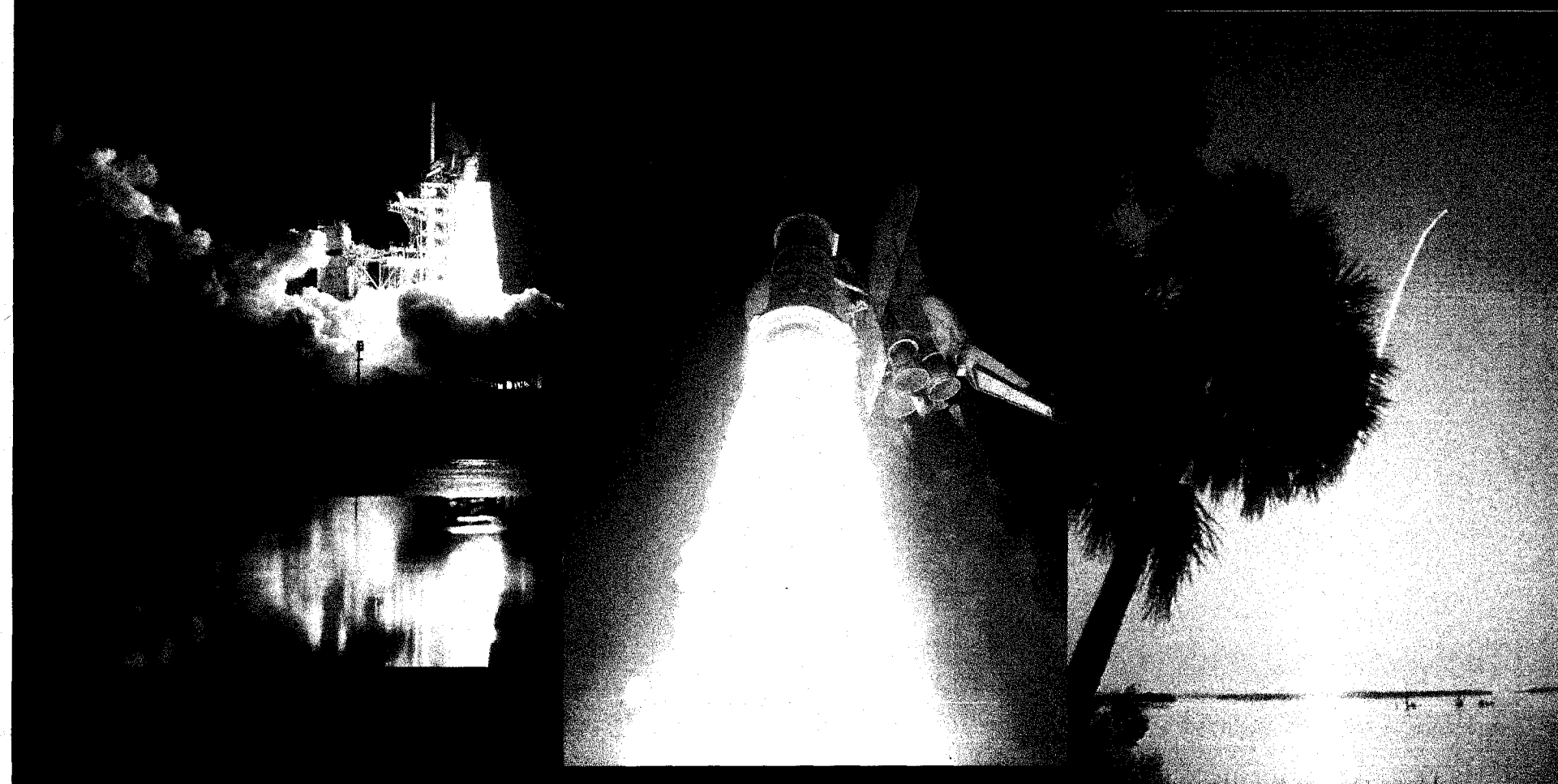




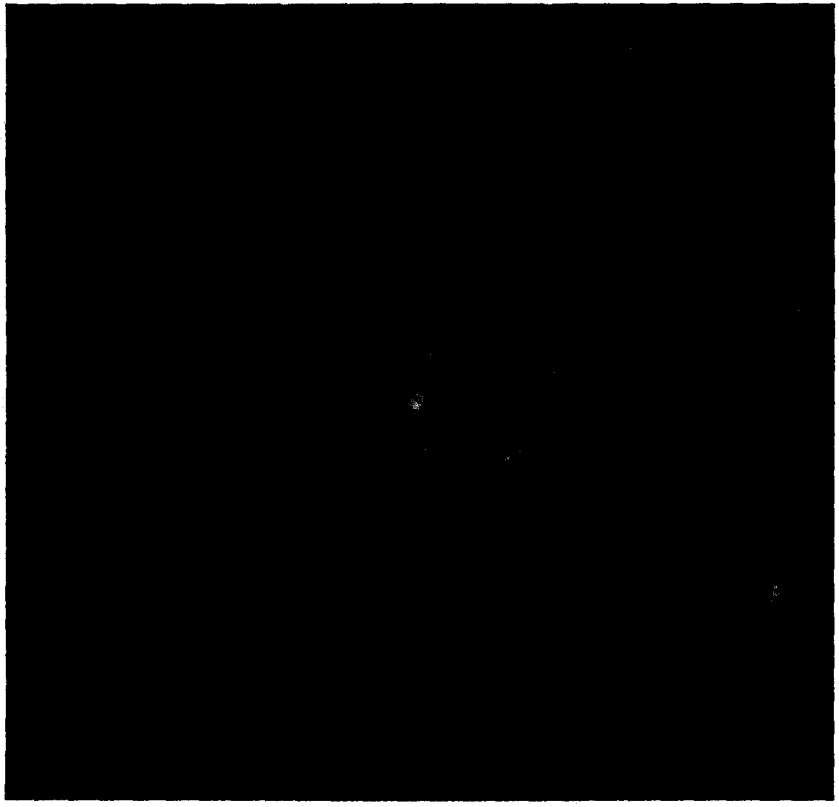
# Three Launch Attempts

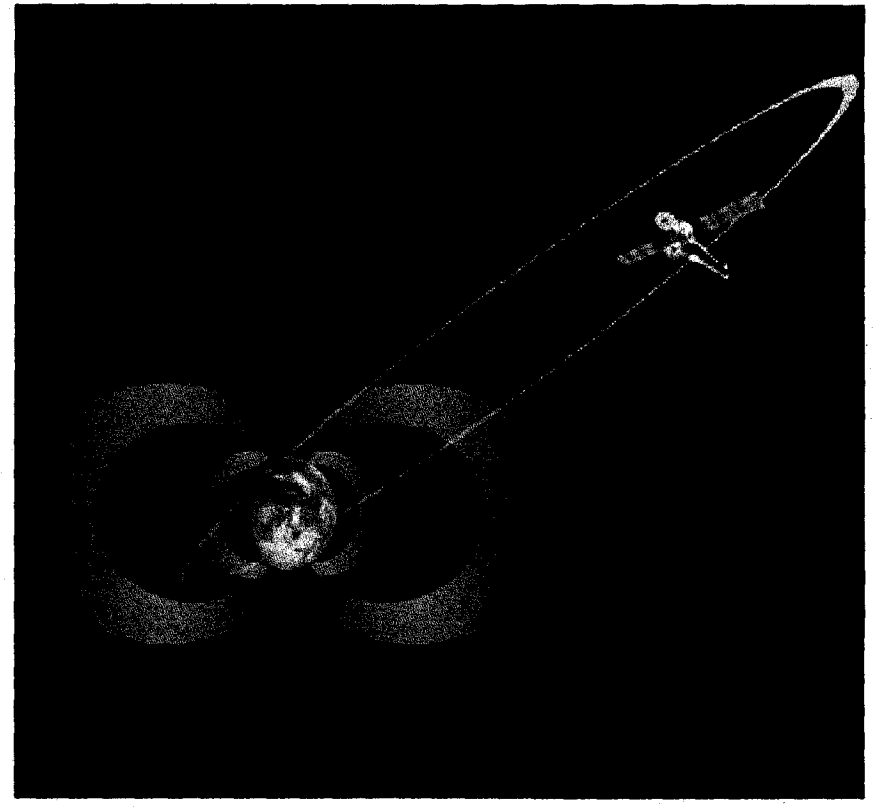
- Mon/Tue July 19/20
  - Sensor spike  hydrogen in the engine compartment
- Wed/Thurs July 21/22
  - Lightning in the vicinity
- Thurs/Fri July 22/23
  - Third time is a charm

# Launch at last! July 23 1999 @ 12:31 a.m.

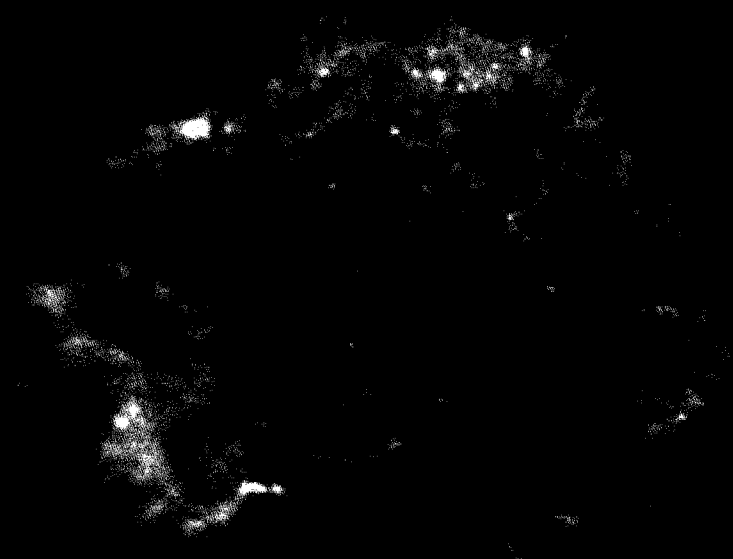


# The Orbit





# First Light – Cas A



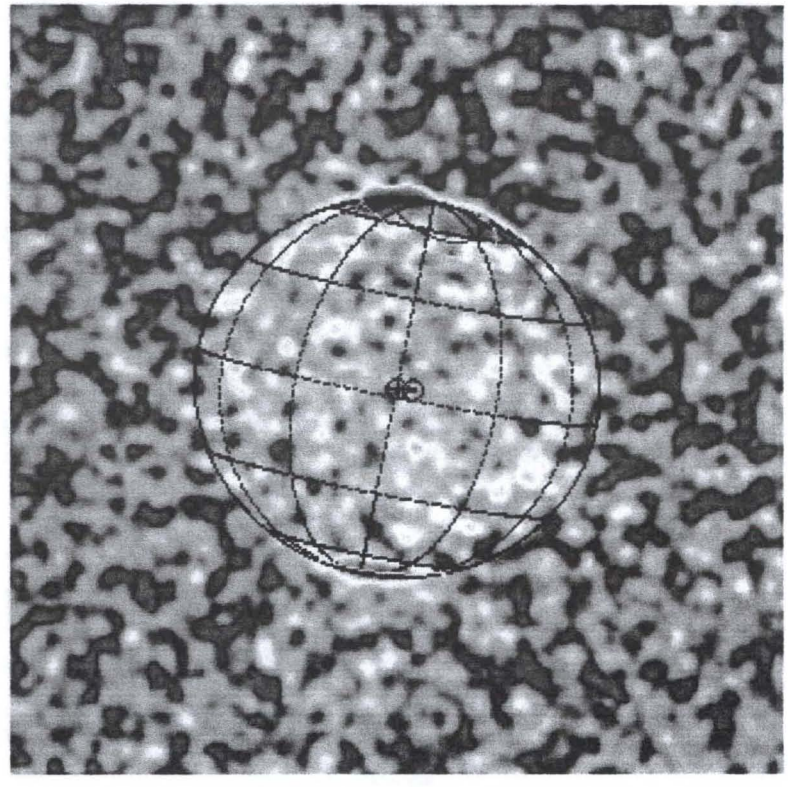
# The Moon


Optical: Robert Gendler; X-ray: NASA/CXC/SAO/J.Drake et al.

# Planets

All planets, other than Uranus, are X-ray sources!

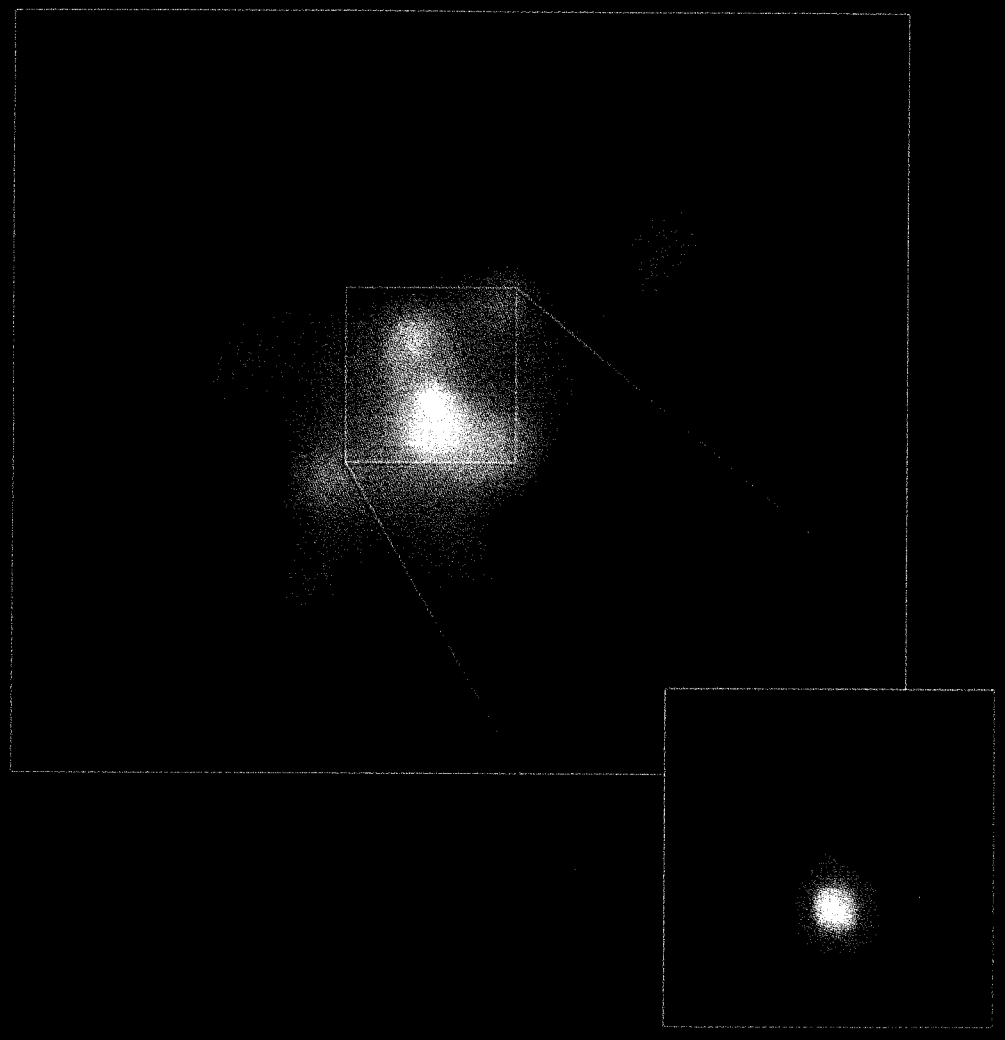
- Jupiter
  - Hot spots at high latitudes
    - *Big surprise*
  - Pulsates (45 minute period)





Gladstone et al.(2002) Elsner et al. (2002)

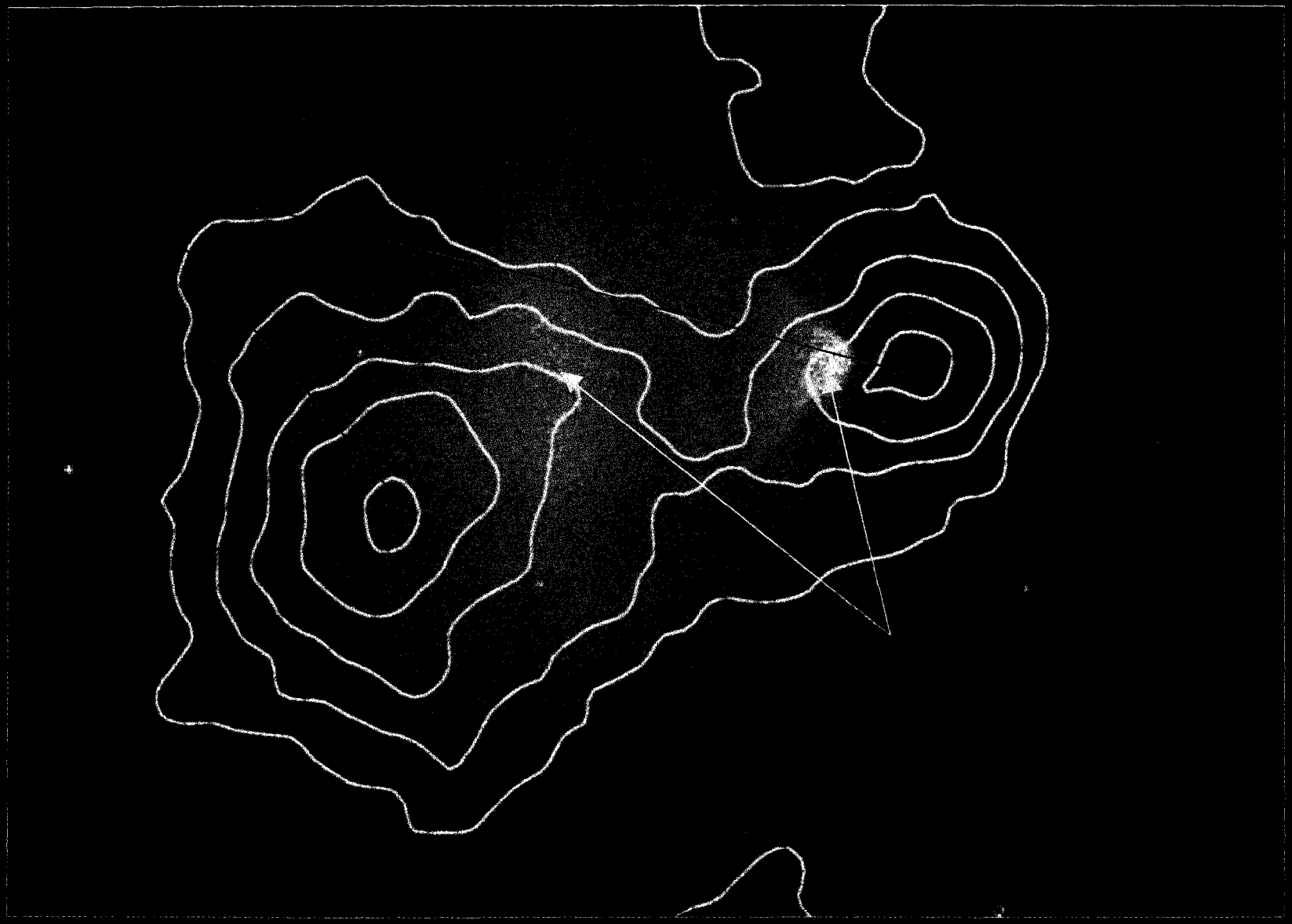
# Double Quasar



AIAA 2007

NASA/CXC/MPE/S.Komossa et al

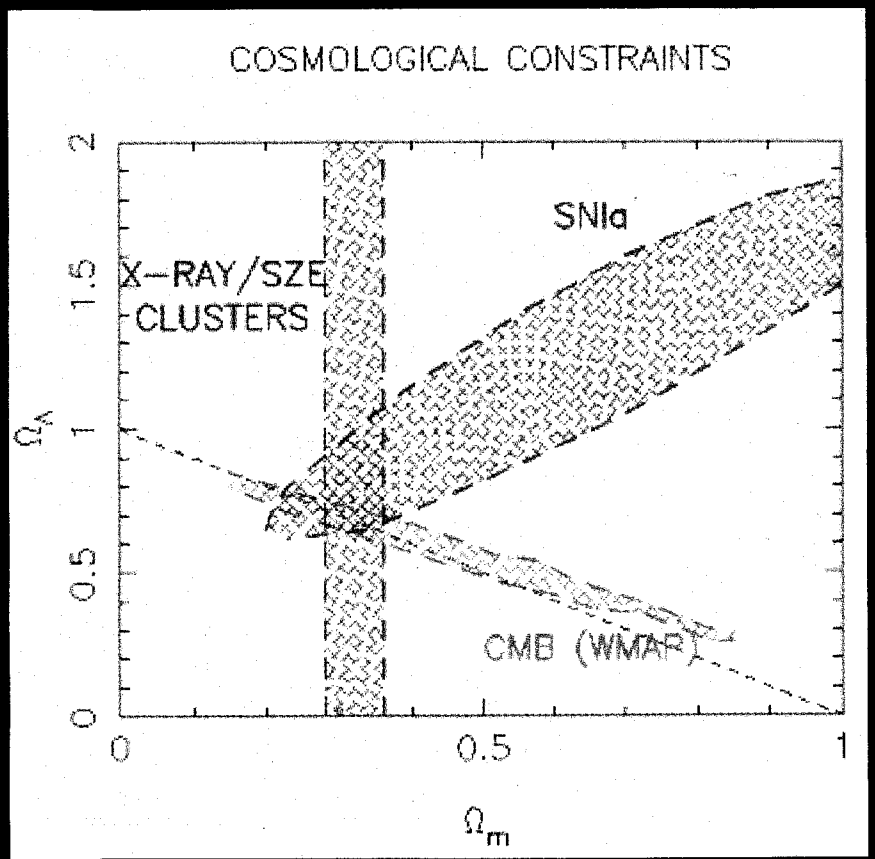
# Dark Matter

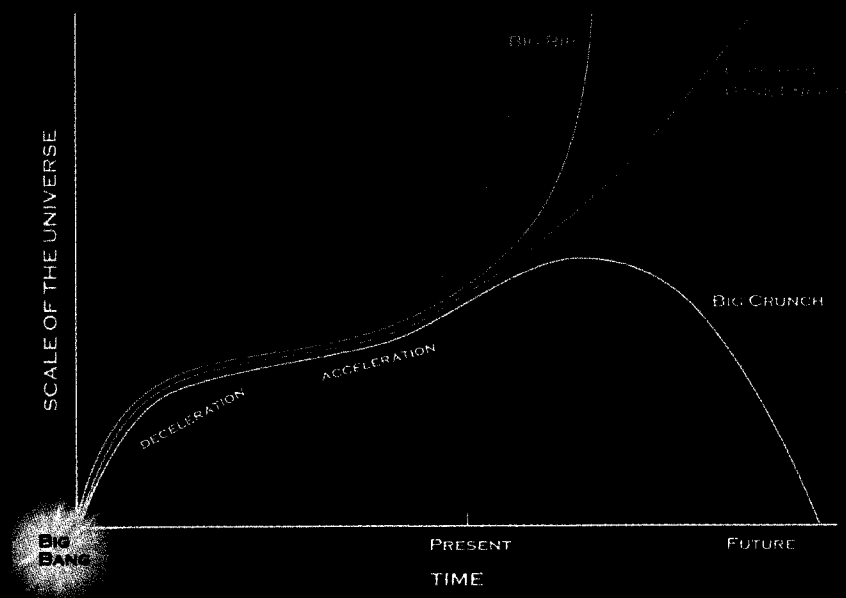


AIAA 2007

1E0657-56 Chandra image with lensing contours

# Dark Matter & Dark Energy



# The Nobel Prize - 2002

# Summary

- Operations are running smoothly
- Mission success
  - Design of the Observatory
  - Excellent and committed staff
  - Team effort
- Exciting and fundamental scientific results
  - Papers at a rate of ~10 per week
- Visit our web site @ www.chandra.harvard.edu

# Chandra Lifetime

- Fuel: >40 years
- Orbit: 30-50 years
- Funding: NASA committed to (at least) a 13 year mission